THE PETROLOGY AND GEOCHEMISTRY OF THE WILIS AND LAWU VOLCANOES, EAST JAVA, INDONESIA

by

Ir. Udi Hartono

(Gadjah Mada University, Indonesia)

Submitted in fulfilment of the requirements
for the degree of
Doctor of Philosophy (Geology)
University of Tasmania

August, 1994

To my wife, Sri, for her understanding and sacrifice, and
my children, Anton, Esti, Danang and Eliza
for their patience.

STATEMENT

This thesis contains the result of research done in the Geology Department, University of Tasmania, between 1989 and 1994. This thesis contains no material which has been accepted or submitted for the award of any other higher degree or graduate diploma in any tertiary institution, and to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis may be made available for loan and limited copying in accordance with the *Copyright Act 1968*.

Udi Hartono

University of Tasmania
August, 1994

THE PETROLOGY AND GEOCHEMISTRY OF THE WILIS AND LAWU VOLCANOES, EASTERN JAVA, INDONESIA

Abstract

The Wilis Volcanic Complex (WVC) and Lawu Volcanic Complex (LVC) are two volcanoes situated in the eastern part of the island of Java, Indonesia. The volcanoes are separated by an east-west distance of about 70 km, and are part of the chain of volcanoes which forms the eastern Sunda volcanic arc, a subduction-related feature that developed along the convergent boundary between the Indian-Australian oceanic plate to the south and Eurasian continental plate to the north.

The eruptive products of the WVC are classified into five groups based on morphostratigraphy and lithology, these are, from oldest to youngest, the pre-caldera Klotok basalt and basaltic andesite, the pre-caldera Pawonsewu andesite, the caldera Ngebel high-Si andesite and dacite, the post-caldera Jeding basalt-andesite, and the post-caldera Argokalangan andesite. Estimated temperatures of crystallisation of WVC magmas are about 1150°C for the basalts, about 1060°C for one olivine-bearing andesite, and range from 1035°C to 950°C for the andesites. Water contents of the magmas seem to have increased from basaltic through andesitic to dacitic. The bulk compositions of the WVC andesites suggest that the magmas may have formed in a relatively deep magma chamber, at depths of 7 - 18 km (equivalent to pressures of 2 - 5 kb), with small amounts of water. The WVC basalts may have began to crystallise at even greater depths, presumably around 30 km (equivalent to pressures ≈ 8 kb), and the dacites may have formed at about 18 km depth, possibly at slightly greater depths than the most andesites.

The geochemical and isotopic characteristics of both the pre-caldera Pawonsewu and post-caldera Argokalangan andesites are consistent with an origin largely by crystal-liquid fractionation from the pre-caldera Klotok basalt parental magma. Early fractionation of Ol+Cpx+Pl+Mg assemblages followed by Opx+Cpx+Pl+Mg±Apt assemblages could have produced the pre-caldera Pawonsewu and post-caldera Argokalangan andesites from Klotok-type basaltic

parental magma. However, whereas both the pre-caldera Pawonsewu and post-caldera Argokalangan andesites seem to have formed under open-system conditions, with the magma chamber being replenished by new magmas, assimilation of some crustal material may have been involved during the generation of the pre-caldera Pawonsewu andesite.

The origin of the caldera Ngebel high-Si andesite and dacite is more difficult to interpret. Major, trace and REE characteristics of the dacite (including High-Si andesite) are not consistent with an origin by simple fractionation from andesite. They may be related petrogenetically to the pre-caldera Klotok basalt/basaltic andesite, despite a silica-gap of about 7 wt % SiO_2. Crystal fractionation involving the separation from Klotok-type basaltic parental magma of assemblages of Ol+Cpx+Pl+Mg followed by either Opx+Cpx+Pl+Mg, Pl+Amp+Mg or Opx+Pl+Amp+Mg, could explain the major element variation from the basalt to dacite. However, $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values increase with increasing SiO_2, Rb and Rb/Sr, and decrease with increasing MgO and Sr contents, suggestive of some crustal contamination during differentiation, and trace element modelling and the extremely high $\delta^{18}O$ (12.1‰ - 13.5‰) values of the amphibole phenocrysts from the dacite suggest that even more complex differentiation processes may have taken place.

The LVC is divided into two groups, i.e. Old Lawu which is characterised by hornblende-bearing andesites and Young Lawu which is composed of olivine-bearing andesites. Unlike Wilis, basalts are not found. The estimated temperatures of crystallisation of the LVC andesites range from 1250°C to 982°C for Old Lawu and from 1320°C to 986°C for Young Lawu. Amphibole-bearing andesite may have formed at depths of 6 - 7 km, whereas the more basic andesite could have formed at greater depths, perhaps up to 18 km. Old Lawu andesite seems to have developed by crystal fractionation in an open-system magma chamber with the magma chamber being replenished by new magmas. Crystal fractionation could also account for the geochemical variation within the Young Lawu andesites, although contamination may have also been partly responsible for the geochemical variations. It is not known whether both Lawu groups came from the same parental magma, or even if their parent was basaltic. A more speculative interpretation suggests that the Young Lawu andesite may have resulted from fractionation of a mantle-derived basaltic parental magma, whereas the Old Lawu andesite more probably derived from a basaltic andesite parental magma produced at the upper mantle - lower crust as a result of reaction between mantle-derived magma and anhydrous ferromagnesian phases.

Zr/Nb, $^{87}Sr/^{86}Sr$ and $^{143/144}Nd$ values of the WVC basalts and the $^{87}Sr/^{86}Sr$ and $^{143/144}Nd$ values of LVC andesites suggest that MORB mantle exists in the mantle wedge beneath these volcanoes. The REE patterns of the WVC basalts and Young Lawu andesites are inconsistent with models calling for residual amphibole in the source region, but may be adequately modelled by melting of spinel lherzolite.

Wheller et al (1987) identified four regional along-arc sectors in the magmatism of the Sunda-Banda arc. They placed the transition from their West Java to Bali sector between Lawu and Wilis and proposed that the geochemical and isotopic differences reflected a greater involvement of crustal material in the sources of the magmatism. It is here argued that these differences arose because the effects of crustal assimilation are more pronounced in the Lawu Volcanic Complex than in the Wilis Volcanic Complex, possibly because the arc crust is thinner under Wilis than beneath Lawu.

Acknowledgments

I wish to thank sincerely many people who have helped me in various ways to complete this thesis.

- Professor Rick Varne proposed this project and he and Dr Tony Crawford have supervised my research throughout my stay in Hobart, encouraged me, and offered constructive criticism where necessary.

- Dr Rab Sukamto (Director of GRDC) encouraged me to study in Australia. Parts of the field-work were sponsored by my institution, GRDC, and a number of people from this institution have been involved, including Mr Baharuddin, Mr Kusnama Brata, Mr Edy Haryono, Mr Sahardjo, Mr Rosyid and Mr Yayat.

- The Australian International Development Assistance Bureau sponsored my study, including field-work in Indonesia. Parts of the field work were also sponsored by the Indonesian-Australian Geological Mapping Project (IAGMP) in Bandung. Mr David Trail, the manager of IAGMP, arranged the K-Ar analyses for my samples through AMDEL. Many of the expenses of my project were met from research funds provided by the University of Tasmania and the Australian Research Council, and Prof R. Varne arranged extra financial support during my few last months in Hobart.

- Drs Andrew (Joe) Stolz and Trevor J Fallon were a great help and were always willing to join in discussion as the thesis progressed.

- Dr Steve Eggins gave me many ideas at the beginning when he was a post-graduate student in the Geology Department. I have appreciated his friendship and encouragement.

- Dr Ron Berry welcomed me and supervised my studies when I first came to Hobart.

- Drs John Foden and Simon Turner of the Department of Geology and Geophysics, University of Adelaide, helped with some of the Sr and Nd isotope analyses. My fellow Indonesian students in Adelaide, Ukat Sukanta and Chamdan Zainal Abidin, offered hospitality when I stayed in Adelaide.

- Mr Phil Robinson, Mr AungPwa and Mrs Nilar Zaw helped with XRF analyses and Sr and Nd isotope separation.

- Mr Wislaw Jablonski gave friendly assistance in using the Cameca SX 50 electron microprobe.

- Mr Simon Stephens and his staff prepared thin sections. Mr Peter Cornish and the secretaries, Mrs Jeanette Hankin and Mrs Julie Beattie, helped in many ways. To them all I offer my thanks.

- Mrs Margaret Eldridge, and a number of people in the International Student Office including Mrs Jan Lansdowne and teachers from ELICOS, including Mrs Clare Fuller and Mrs Louise Oxley, frequently proof-read the text.

- Many post-graduate students and research fellows in the Geology Department were generous with their friendship and discussion. I should mention in particular all the students who shared the room with me at the Department, including Salman, Baharuddin, Tannis Wongwanis, Ingvar Sigurdsson, John Dunster, Mohammad Adabi, and many others, including Russell Fulton, Alicia Verbeeten, Massimo Gasparon, Greg Yaxley, Geoff Nicholls, Mike Seitz, Andrew McNeill, Rahmat Hermanto, Soetijoso Djojomiharjo, Safra Dwipa, Fernando Della Pasqua, Marcel Kampermann Drs Russel Sweenney, Leonid Danyushevky, Vadim Kamenetski, Kin Zaw, Paul Kitto, Ai Yang, Sampan Singarajwarapan.

- Finally, my fellow Indonesians have been most supportive. Special thanks to Yudi (and his wife Tika), Koeswardiyanto, Razi, Yos, and Bimo.

CONTENTS